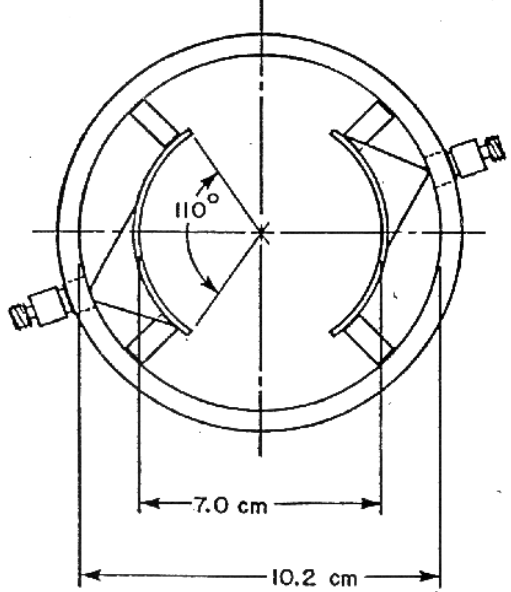

Tevatron Beam Position Monitor Upgrade

Stephen Wolbers
(for the Tevatron BPM Upgrade Project)

PAC05, Knoxville, TN
May 16-20, 2005

Outline

- Motivation for TeV BPM Upgrade
- TeV BPM Upgrade Design and Implementation
- Performance of New BPM System
- Conclusions

Motivation for Upgrade

- Old Tevatron BPM electronics was not accurate, precise or reliable enough for the Tevatron, nor was it able to measure pbar positions.
  - Old system was built in the early 1980's and is showing its age.
  - Resolution of 150 microns.
  - Uses old networking/controls protocols
  - No pbar position measurements.
- Pickups in the tunnel not to be modified!

New System Requirements

- Stable, accurate, precise measurements.
  - Aiming for <10 micron (1 sigma) precision for best proton position measurement.
- Reliable hardware and software.
- Software to collect and use the data.
- Measurement of antiproton positions (new capability).
  - Requires that both ends of pickups be instrumented (twice as many electronics channels).
  - Turn-by-turn (wide-band) and closed orbit (narrow-band) position measurements

Key Specifications (Protons):

Measurement Range: ±15mm
Absolute Position Accuracy: < 1.0 mm
Long Term Position Stability: < 0.05 mm
Best Orbit Position Resolution: < 0.02mm
Position Linearity: < 1.5%
Relative Position Accuracy: < 5%
Intensity Stability: < 2%

Key Specifications (Pbars):

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Absolute Position Accuracy: < 1.0 mm
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Best Orbit Position Resolution: < 0.05mm
Position Linearity: < 1.5%
Relative Position Accuracy: < 5%
Intensity Stability: < 2%

System Design

- **Position measurement**
  - The 53 MHz component of the BPM signal is used to measure position.
- **Analog signal**
  - The analog signal is filtered and attenuated on a special purpose filter board. The bandpass filters are 53 MHz with width of 7 MHz.
  - An impulse response time of 400ns was required to allow for pbar measurements using timing (rather than proton signal subtraction)
    - See Poster/Paper from Bob Webber for details of the timing technique.

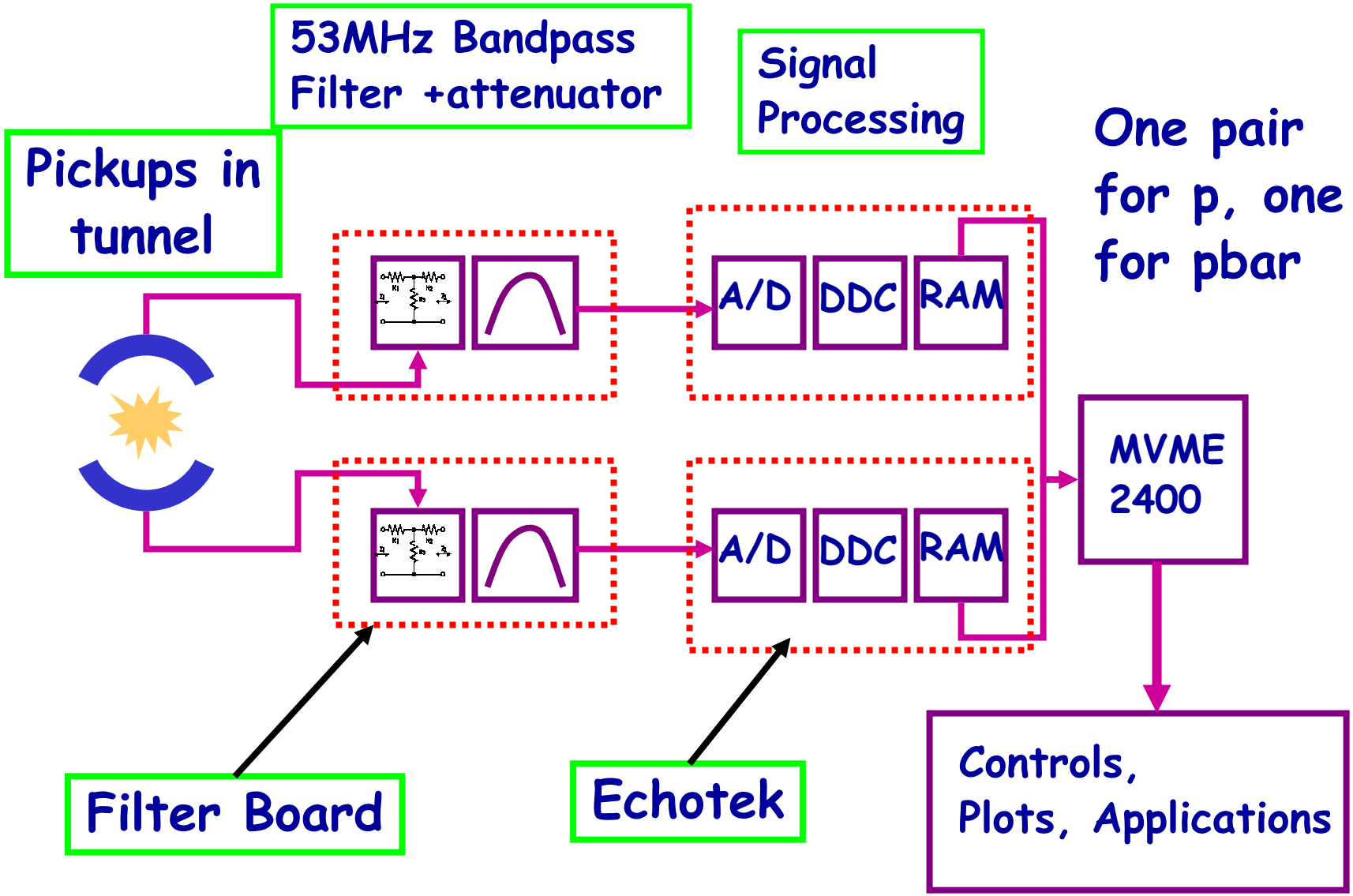
System Design

- **Technology:**
  - A decision was made to use essentially the same digitizer board (made by Echotek Corp.) as was used in the Recycler BPM upgrade.
  - This board was also chosen for the NUMI, transfer line, and Main Injector BPM upgrades.
    - See poster from Gustavo Cancelo for details about digital filtering.

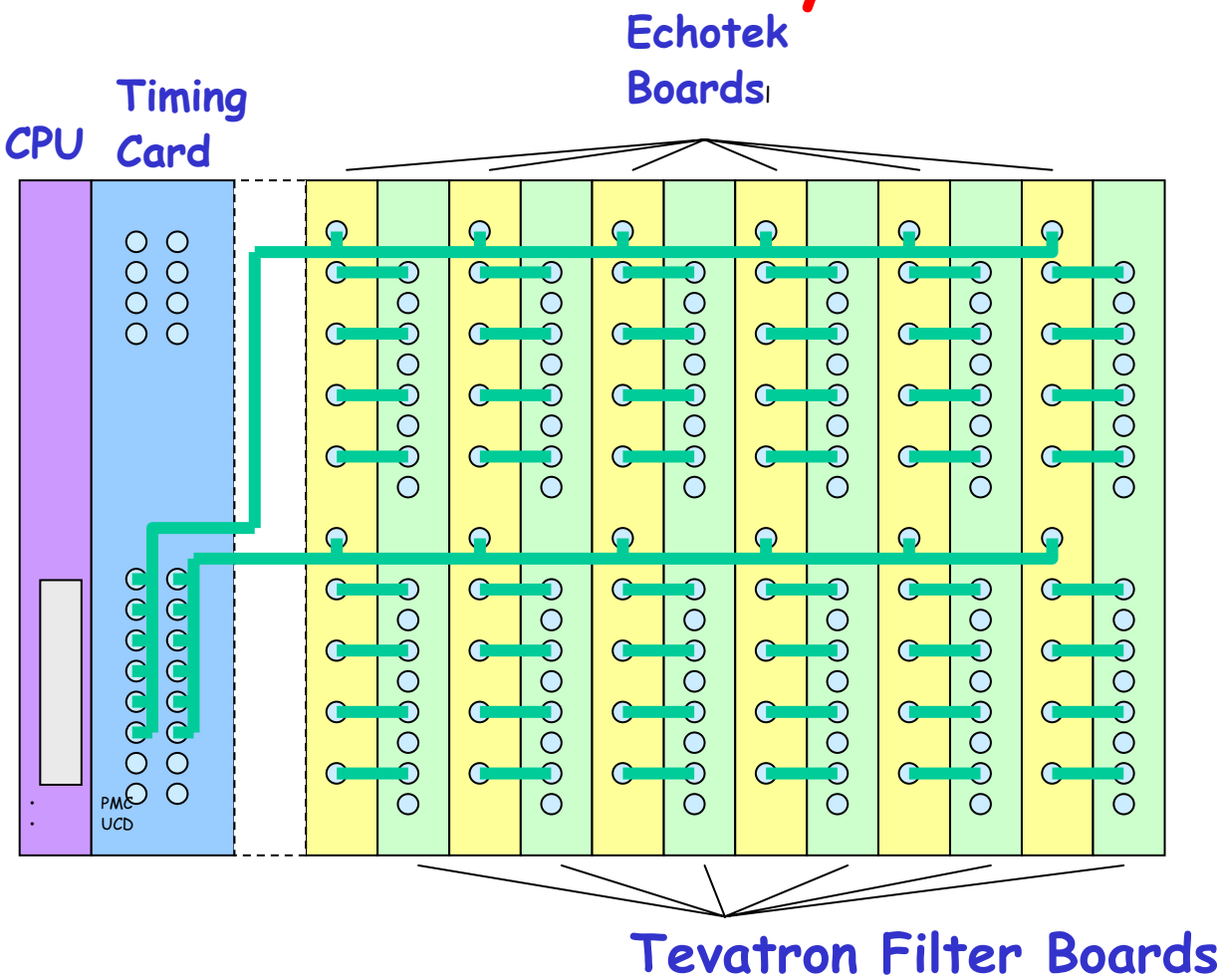
System Design

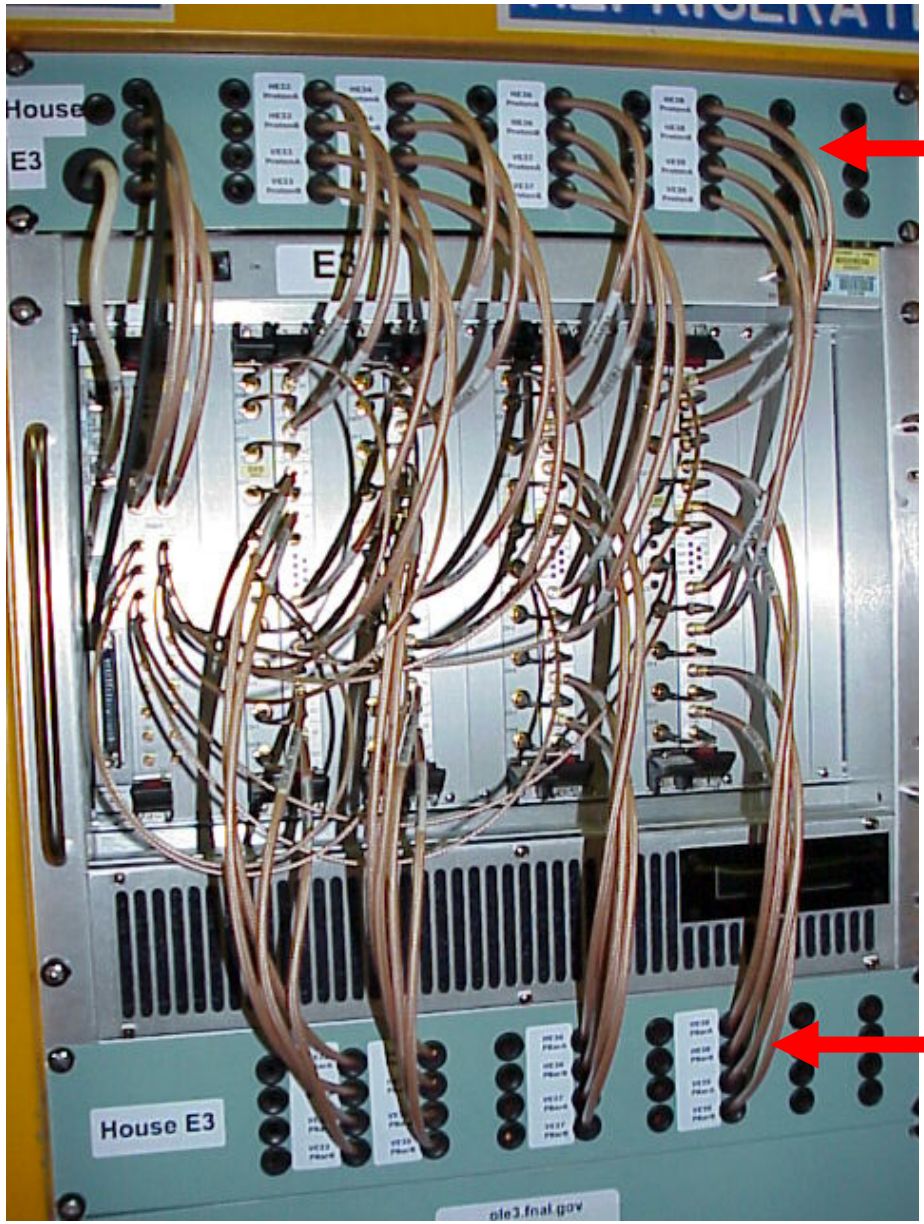
- **Anti-proton position measurements:**
  - The pickups in the Tevatron have directionality of 26dB.
  - Both ends are read out with the new Tevatron BPM electronics.
  - The proton signal (currently) is significantly larger (factor 6) than the antiproton signal.
  - Even with the 26dB directionality, the antiproton ends of the pickups see approximately equal contributions from antiproton and proton and we need to separate them to make antiproton measurements (in frequency space).
    - See Rob Kutschke's poster/paper for details of the proton cancellation technique.

Block Diagram – vertical BPM



VME Crate Layout





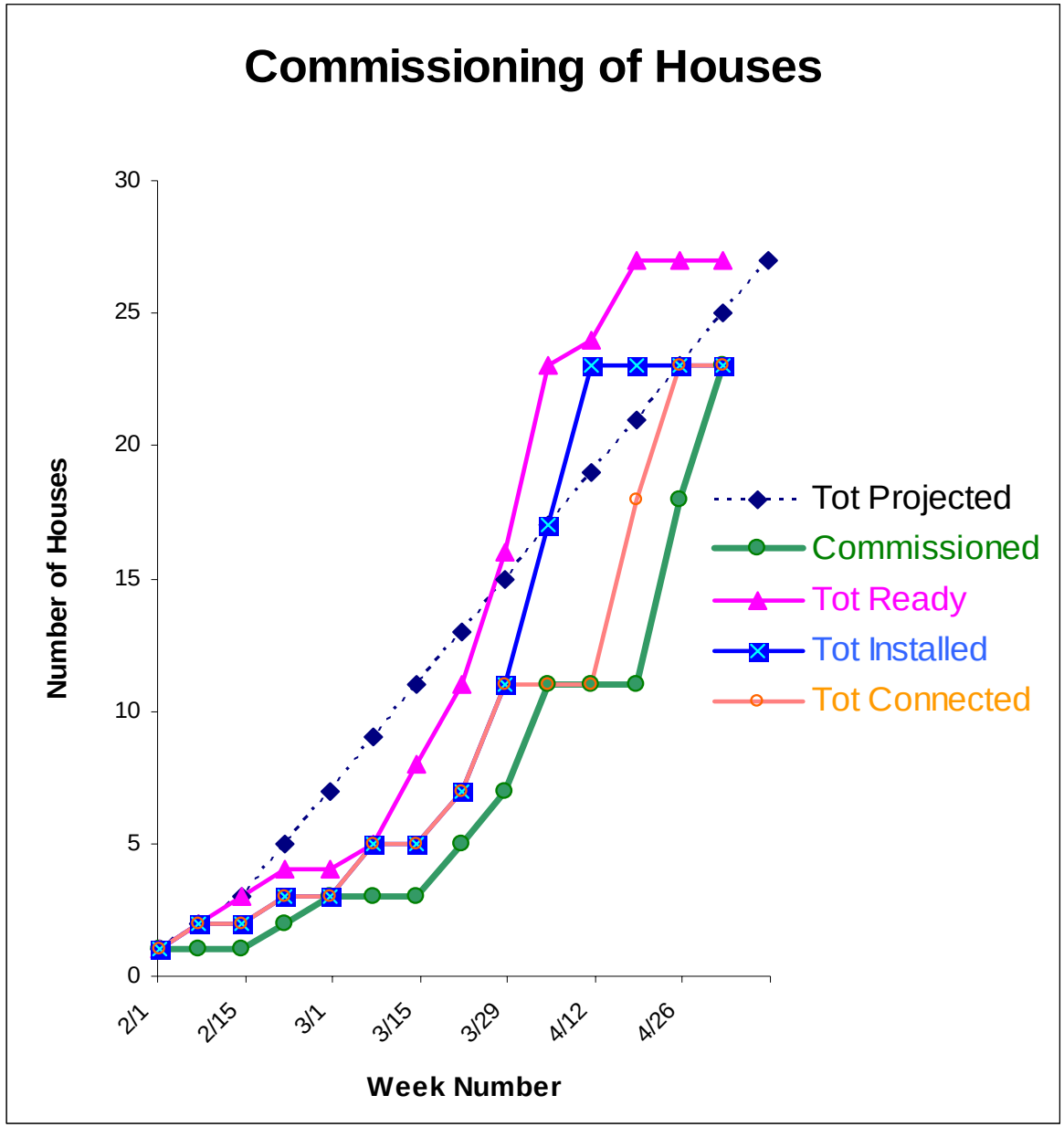
Proton Signals

E3 House in the Tevatron

Pbar Signals

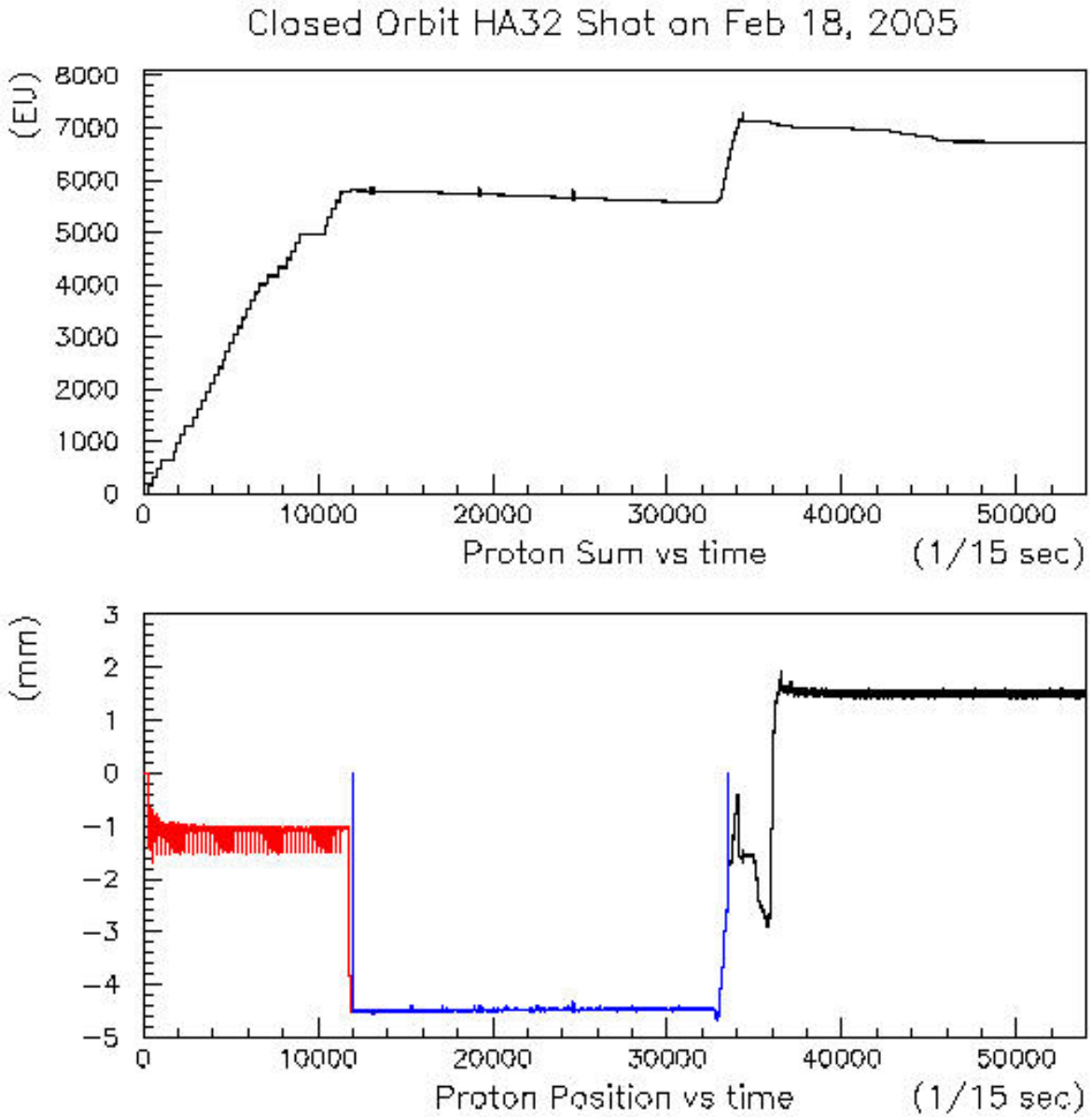
Project Dates

- 9/22/03: Requirements review
- 12/19/03: Technology choice review
- 3/11/04: Place Echotek Order
- 5/14/04: Electronics Design Review
- 8/20/04: First Production Echotek boards arrive
- 8/6/04: Install prototype crate in Tevatron
- 11/23/04: Install first production system in A3
- 2/7/05: Finish commissioning A3
- 5/15/05: Finish commissioning all 27 systems


Commissioning of Houses
Number of Houses
30
25
20
15
10
5
0
2/1
2/15
3/1
3/15
3/29
4/12
4/26
Week Number
Tot Projected
Commissioned
Tot Ready
Tot Installed
Tot Connected

System Performance

- **Closed orbit**
  - Average over all bunches and over many turns (1 KHz bandwidth)
  - Proton and anti-proton positions
  - Best resolution ~ 7-10 μm
- **Antiproton measurement via proton signal deconvolution**
  - Coupling of proton to antiproton end of the BPM can be measured.
    - Helix opening, protons only.
  - This coupling can be used to subtract the proton contamination on the antiproton end of the BPMs.



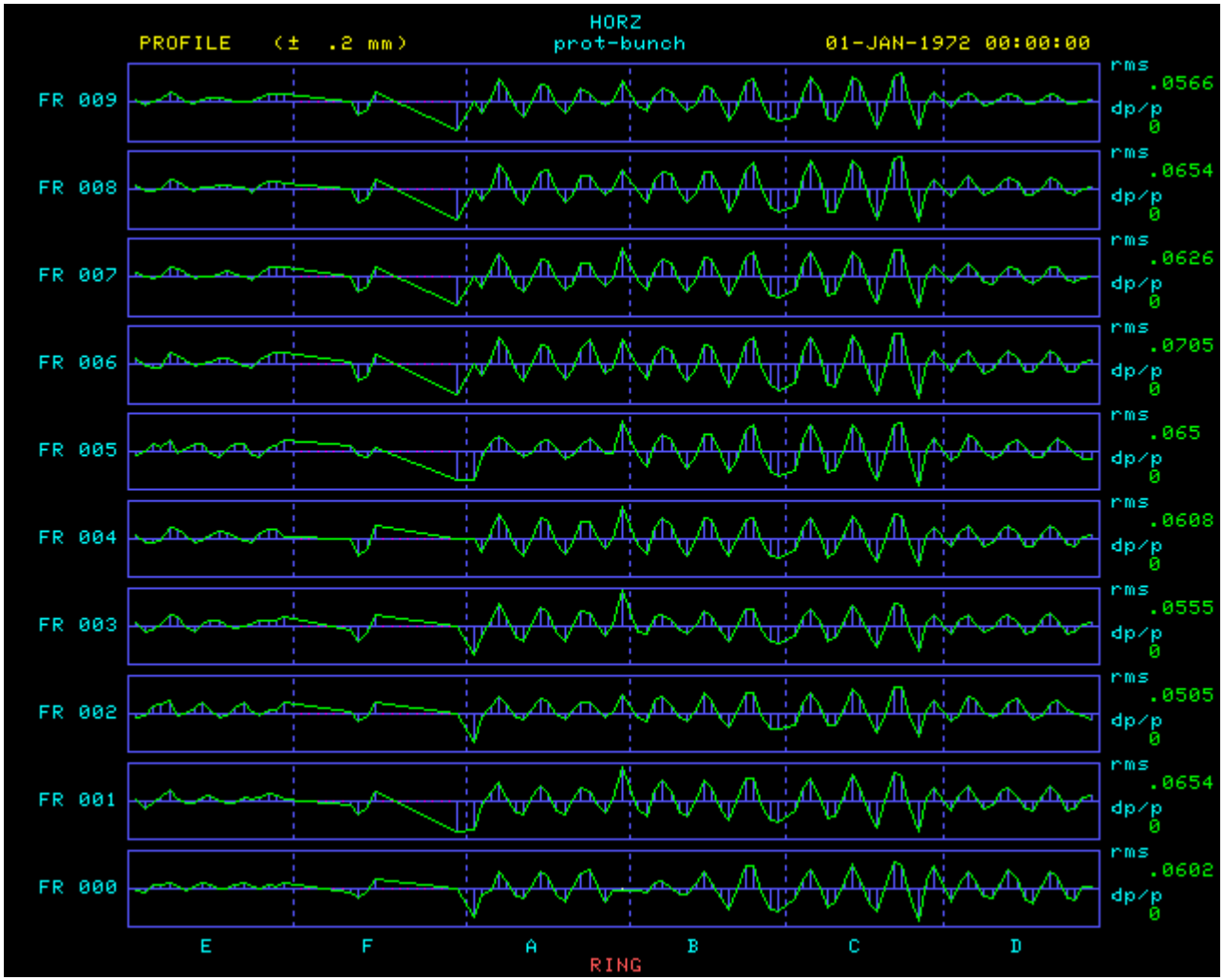
$$Sum = |A| + |B|$$

$$A = (I_A, Q_A)$$

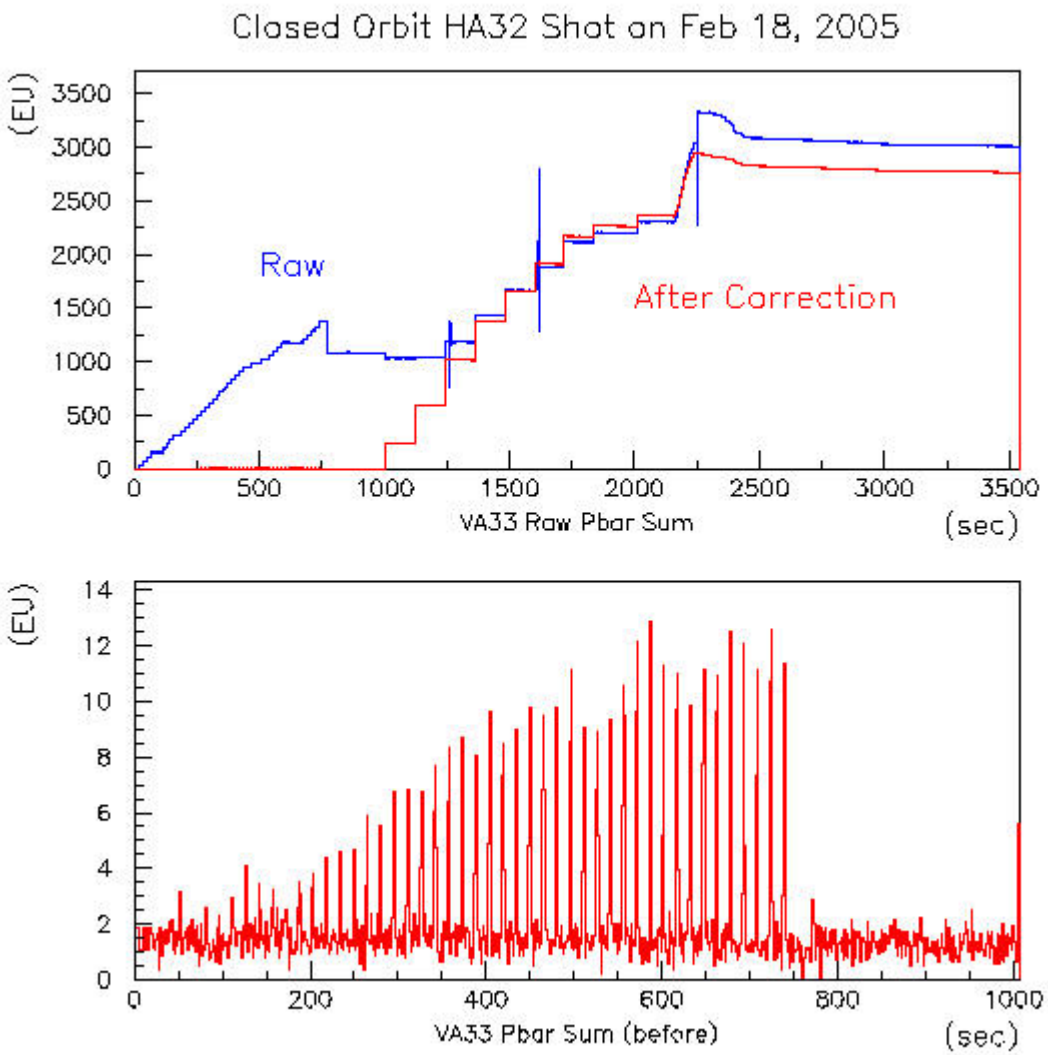
$$B = (I_B, Q_B)$$

$$P = 26\frac{|A| - |B|}{|A| + |B|}$$

Ring-wide performance



Pbar Position Measurement Technique



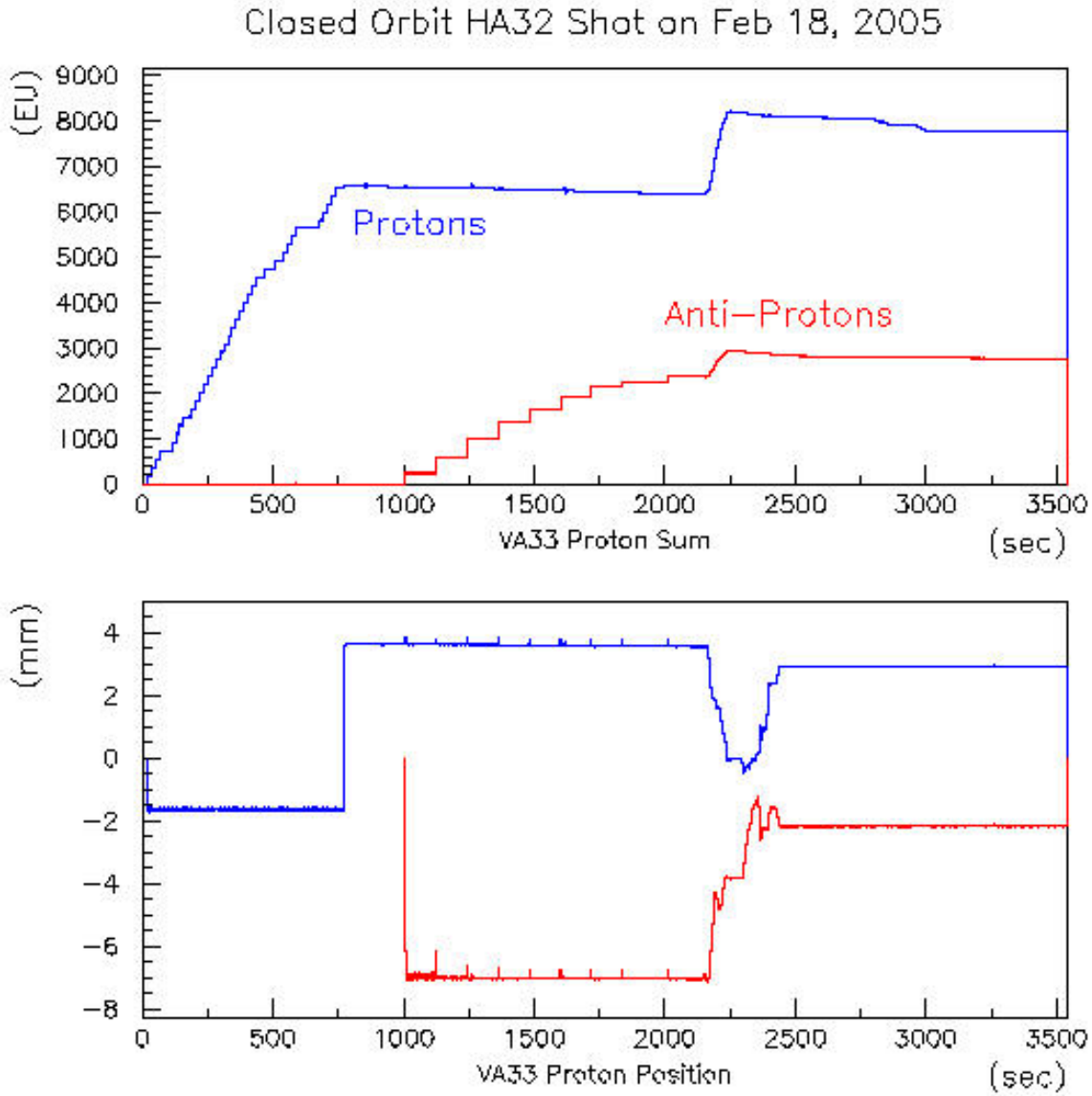
Cancellation of proton contamination on Pbar cables:

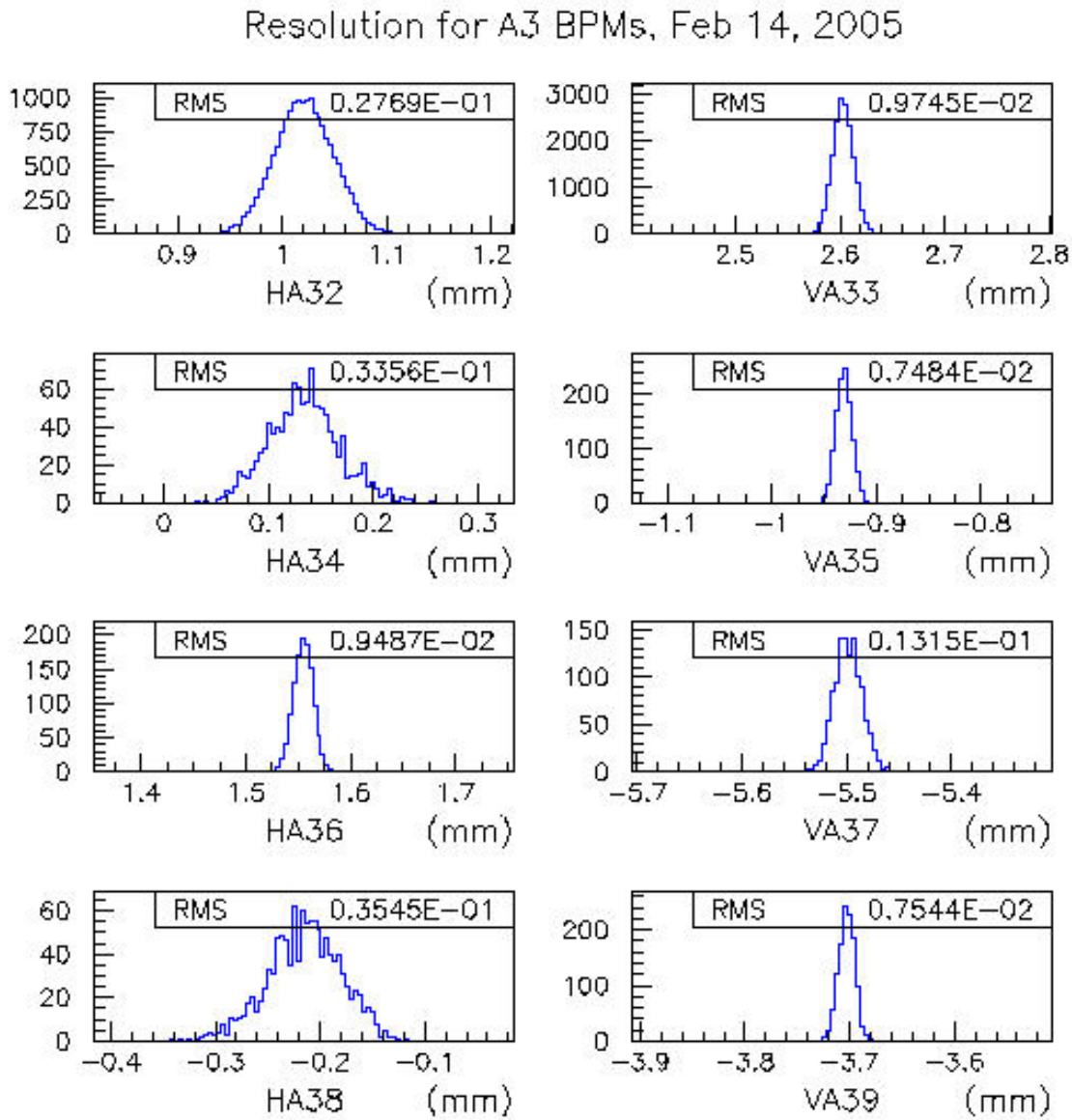
$$A'_{Pbar} = A_{Pbar} - aA_P - bB_P$$

$$B'_{Pbar} = B_{Pbar} - cB_P - dA_P$$

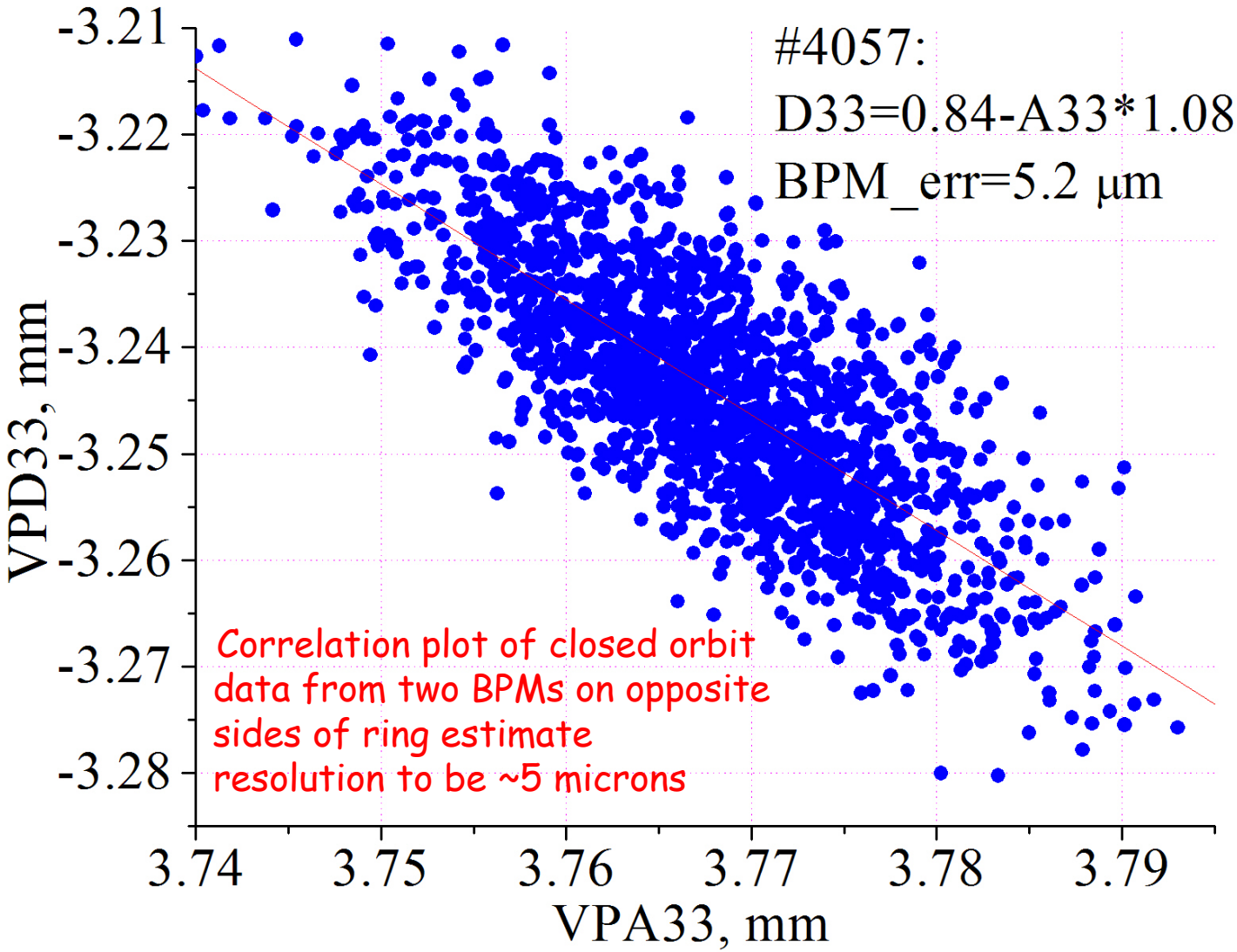
a,b,c,d determined empirically using the opening of the helix.

Using corrected values, compute sum and position as for protons.


Closed Orbit HA32 Shot on Feb 18, 2005
(EU)
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Protons
Anti-Protons
0
500
1000
1500
2000
2500
3000
3500
VA33 Proton Sum
(sec)
(mm)
4
2
0
−2
−4
−6
−8
0
500
1000
1500
2000
2500
3000
3500
VA33 Proton Position
(sec)

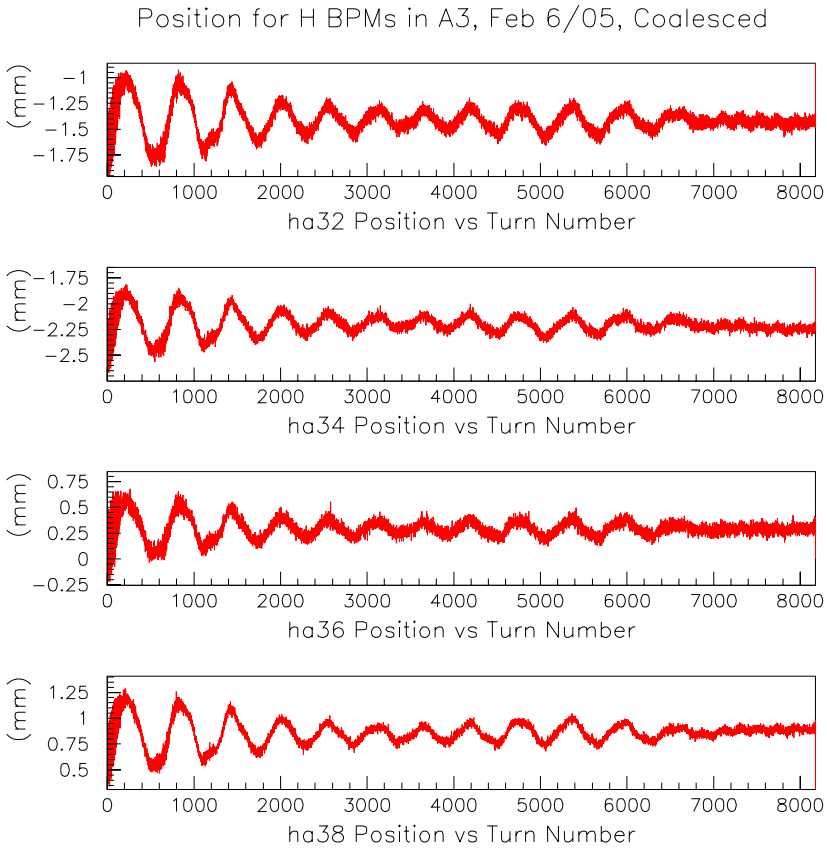

Resolution for A3 BPMs, Feb 14, 2005
RMS 0.2769E−01
HA32 (mm)
RMS 0.9745E−02
VA33 (mm)
RMS 0.3356E−01
HA34 (mm)
RMS 0.7484E−02
VA35 (mm)
RMS 0.9487E−02
HA36 (mm)
RMS 0.1315E−01
VA37 (mm)
RMS 0.3545E−01
HA38 (mm)
RMS 0.7544E−02
VA39 (mm)

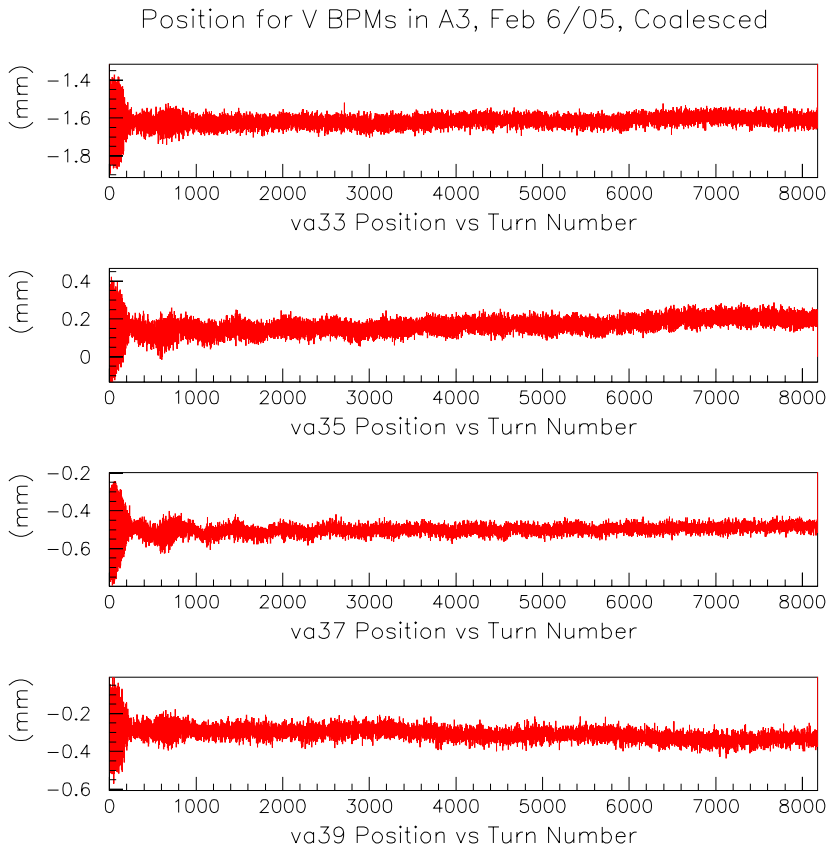
TeV BPM – 36 Bunch Closed Orbit Resolution



System Performance

- **Turn by turn**
  - Injection, 150 GeV
  - Single bunch or uncoalesced beam
  - Can see synchrotron motion, betatron motion, quadrupole oscillations of bunch in the bucket, HV coupling, plus some instrumental artifacts

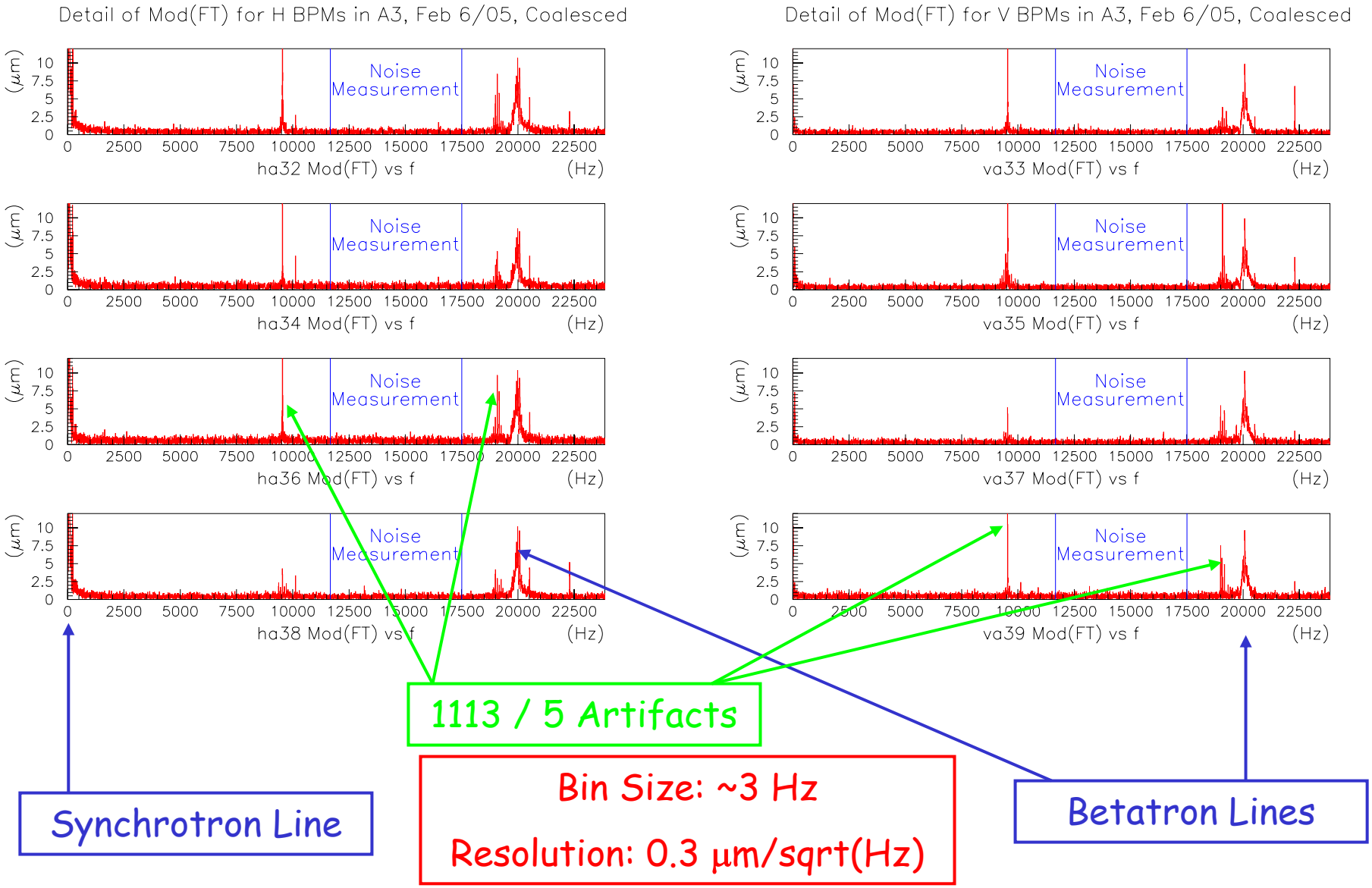


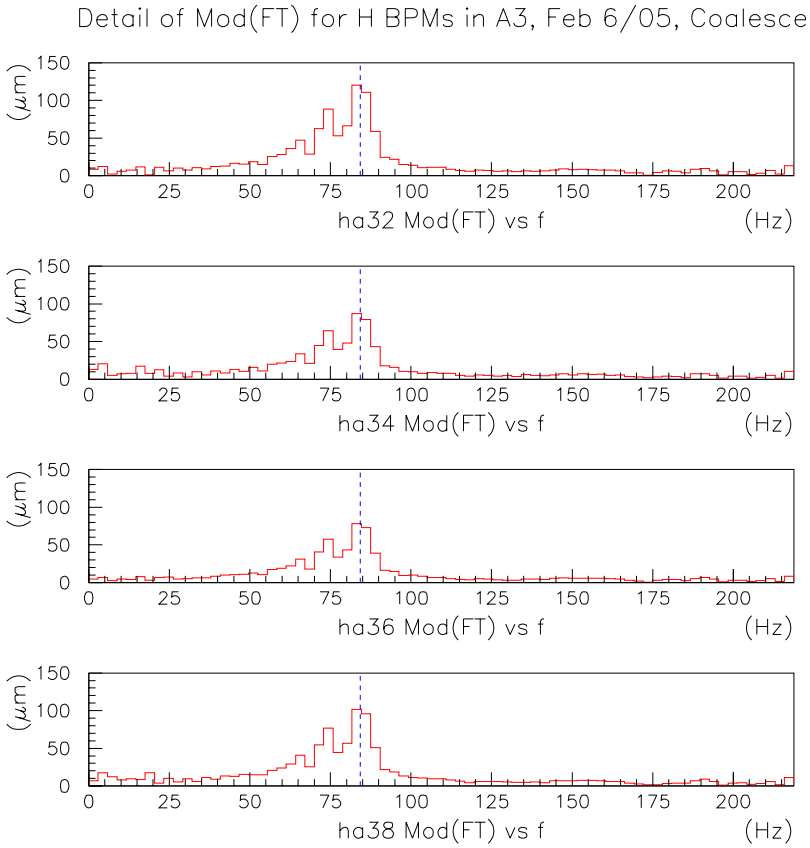


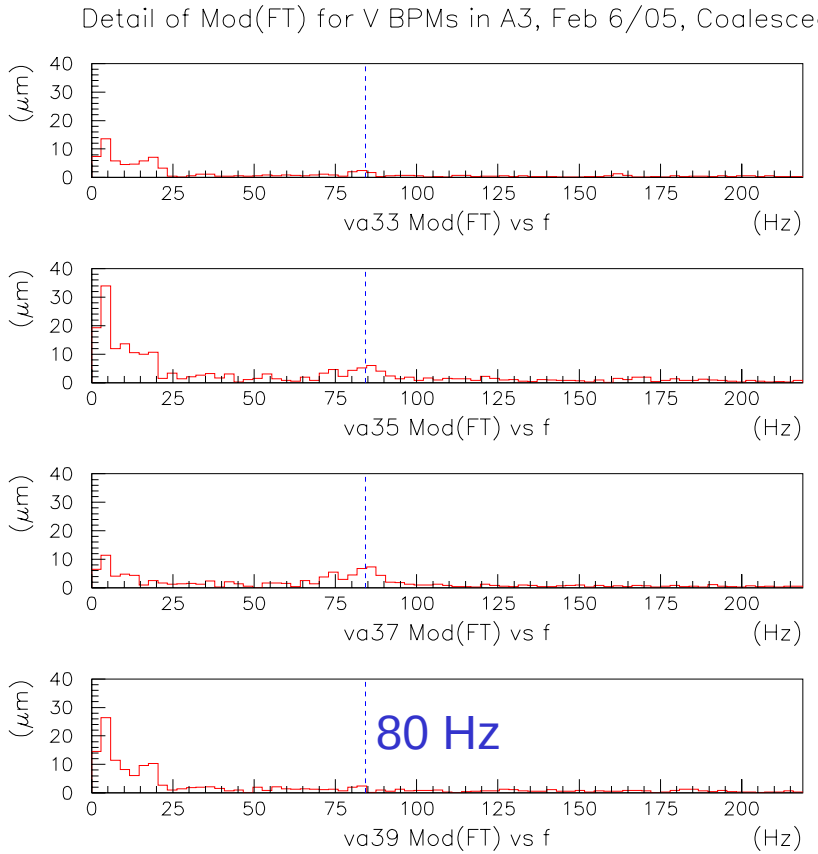
1.1 mm full vertical scale

0.6 mm full vertical scale

- Injection TBT; 150 GeV; 8192 turns.
- One coalesced bunch. HEP shot after all tuning.


Detail of Mod(FT) for H BPMs in A3, Feb 6/05, Coalesced
Detail of Mod(FT) for V BPMs in A3, Feb 6/05, Coalesced
Noise Measurement
ha32 Mod(FT) vs f
ha34 Mod(FT) vs f
ha36 Mod(FT) vs f
ha38 Mod(FT) vs f
va33 Mod(FT) vs f
va35 Mod(FT) vs f
va37 Mod(FT) vs f
va39 Mod(FT) vs f
(μm)
(Hz)
1113 / 5 Artifacts
Bin Size: ~3 Hz
Resolution: 0.3 μm/sqrt(Hz)
Synchrotron Line
Betatron Lines





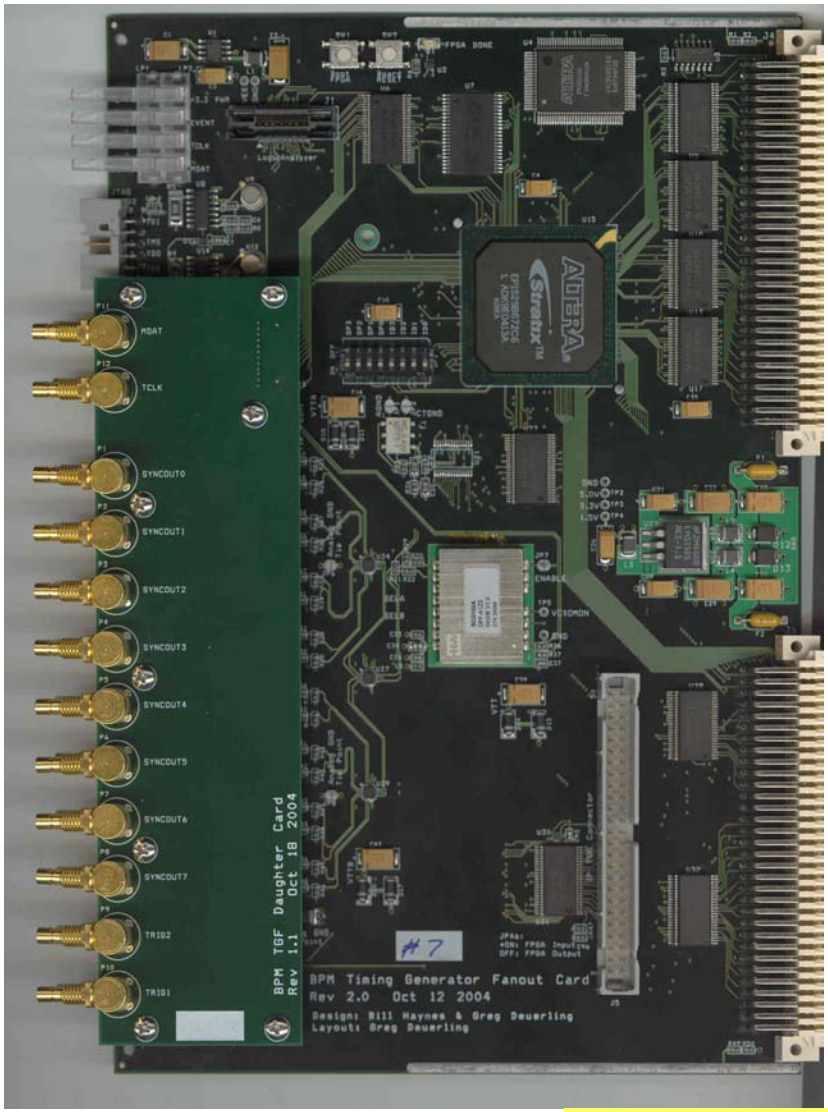
- Synchroton line present in H but not V.
- 150 GeV expected sync frequency: 80 Hz.

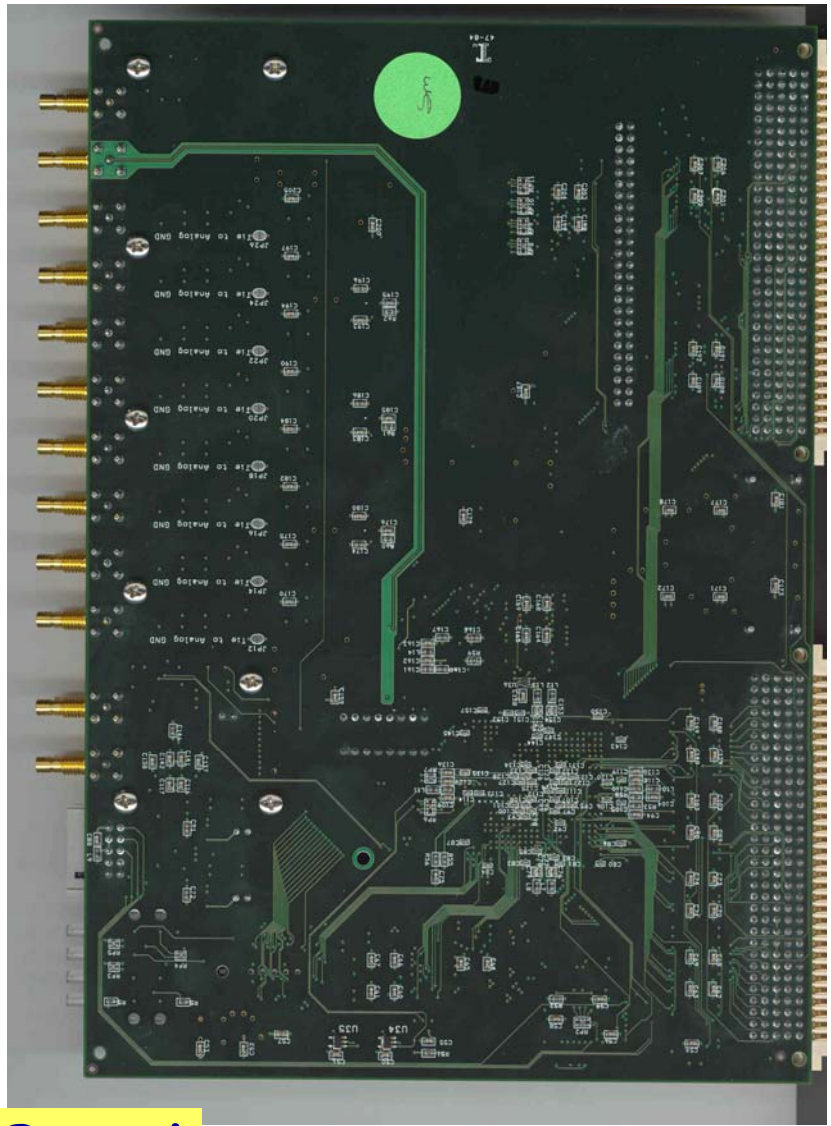
Conclusions

- The Tevatron BPM Upgrade IS successfully installed and commissioned.
- Work continues on final calibration, diagnostics, pbar measurements, documentation.
- The successful BPM upgrade is a result of the work of many people in the Computing and Accelerator Divisions at Fermilab.

Extra slides

Timing Board



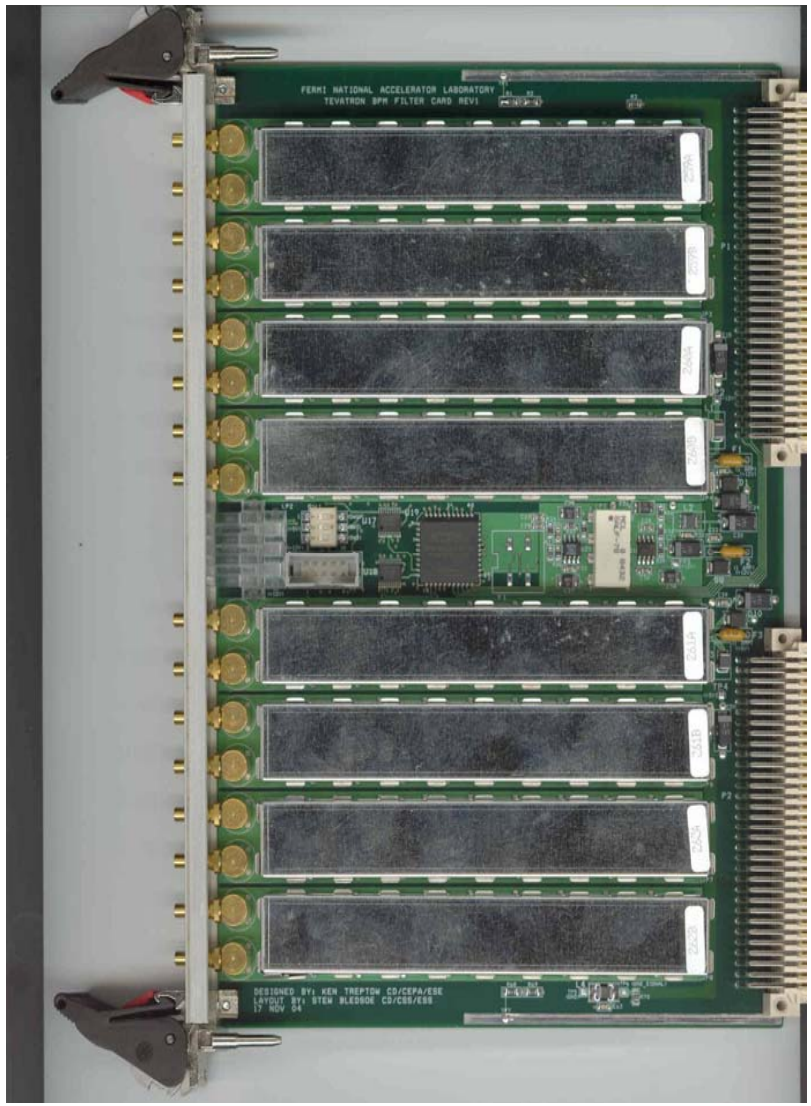


Production Board

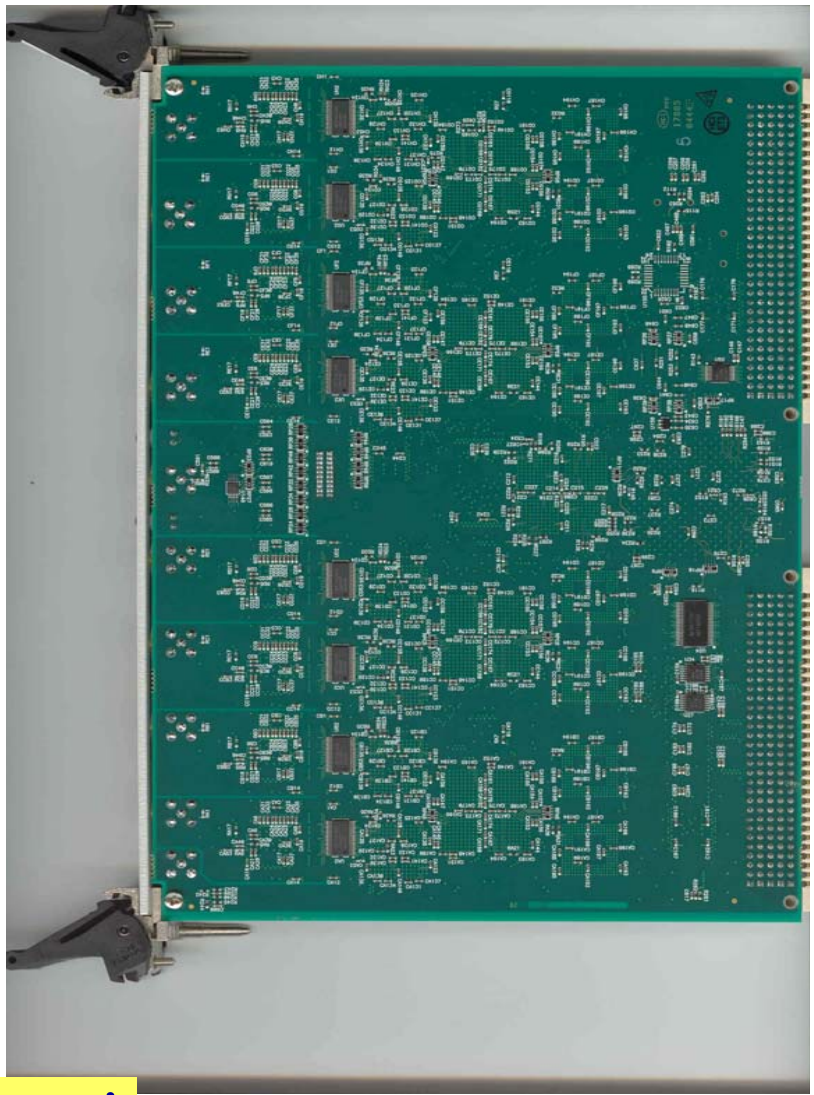
Filter Board

- 8 channels
- 53 MHz band-pass filter
- Attenuation Circuit
- Relays/53 MHz diagnostic signal
- Shielding

Production Board

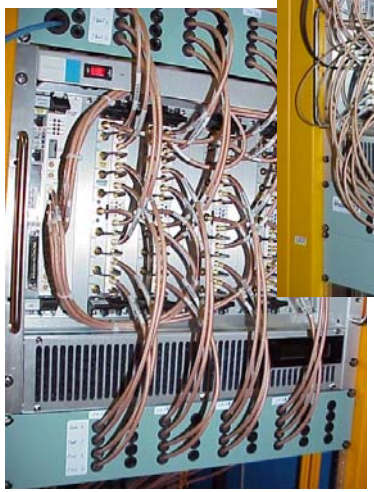


Echotek Board



Production Board

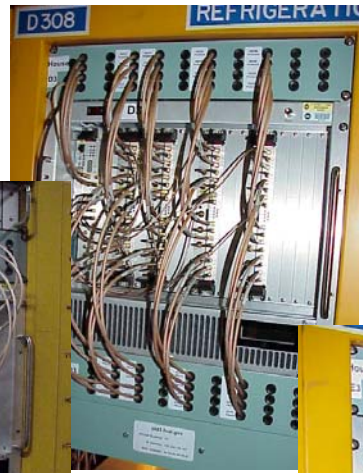
Systems are going in!



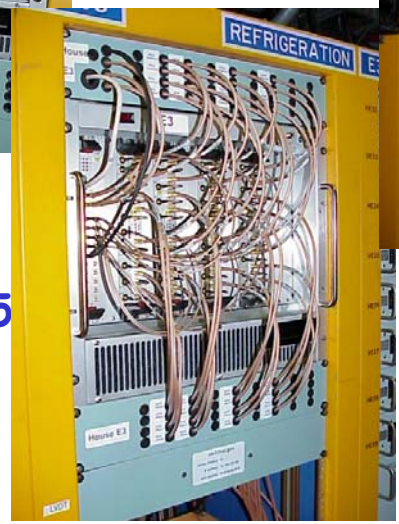
A3
11/22/04

B3
2/10/05

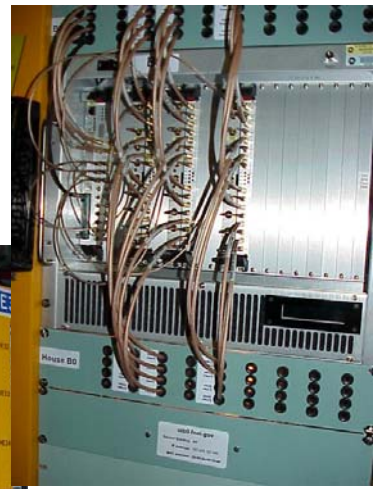
C3
2/23/05



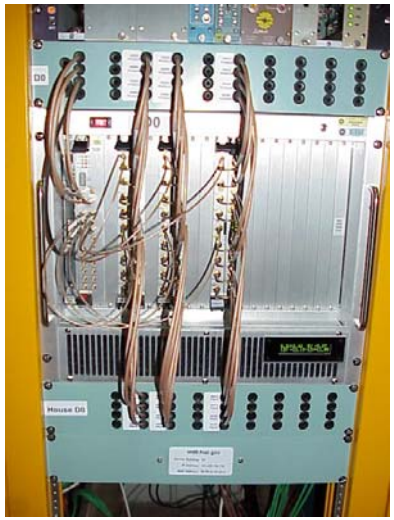
D3
3/08/05



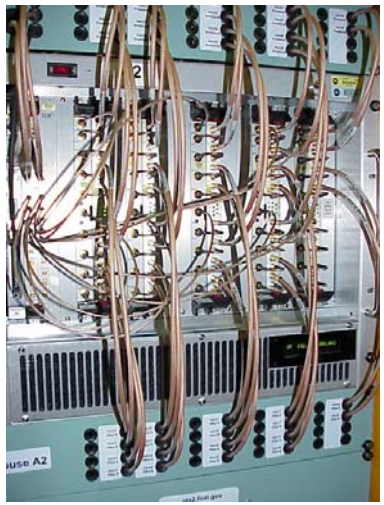
E3
3/11/05



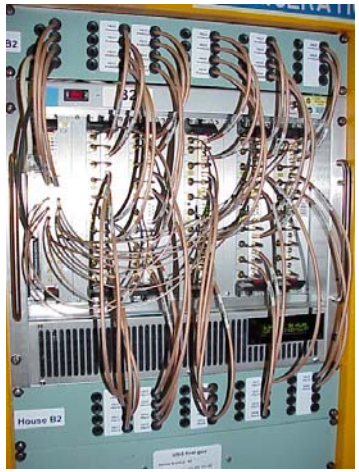
B0
3/23/05



D0
3/24/05



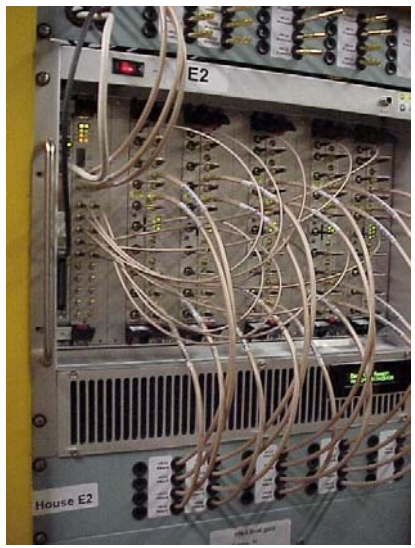
A2
3/30/05



B2
3/30/05

C2
3/30/05

D2
3/30/05

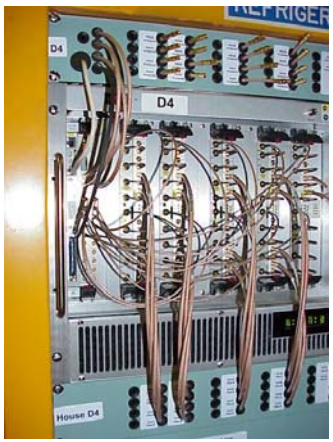


E2
3/30/05

One Day's Work!

E2
4/8/05

F2
4/8/05



D4
4/8/05

A4
4/8/05

B4
4/8/05

C4
4/8/05

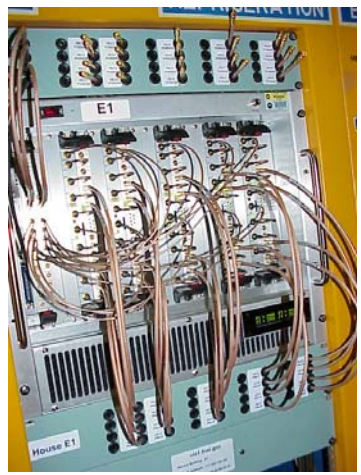
A1
4/11/05

E4
4/11/05

B1
4/15/05

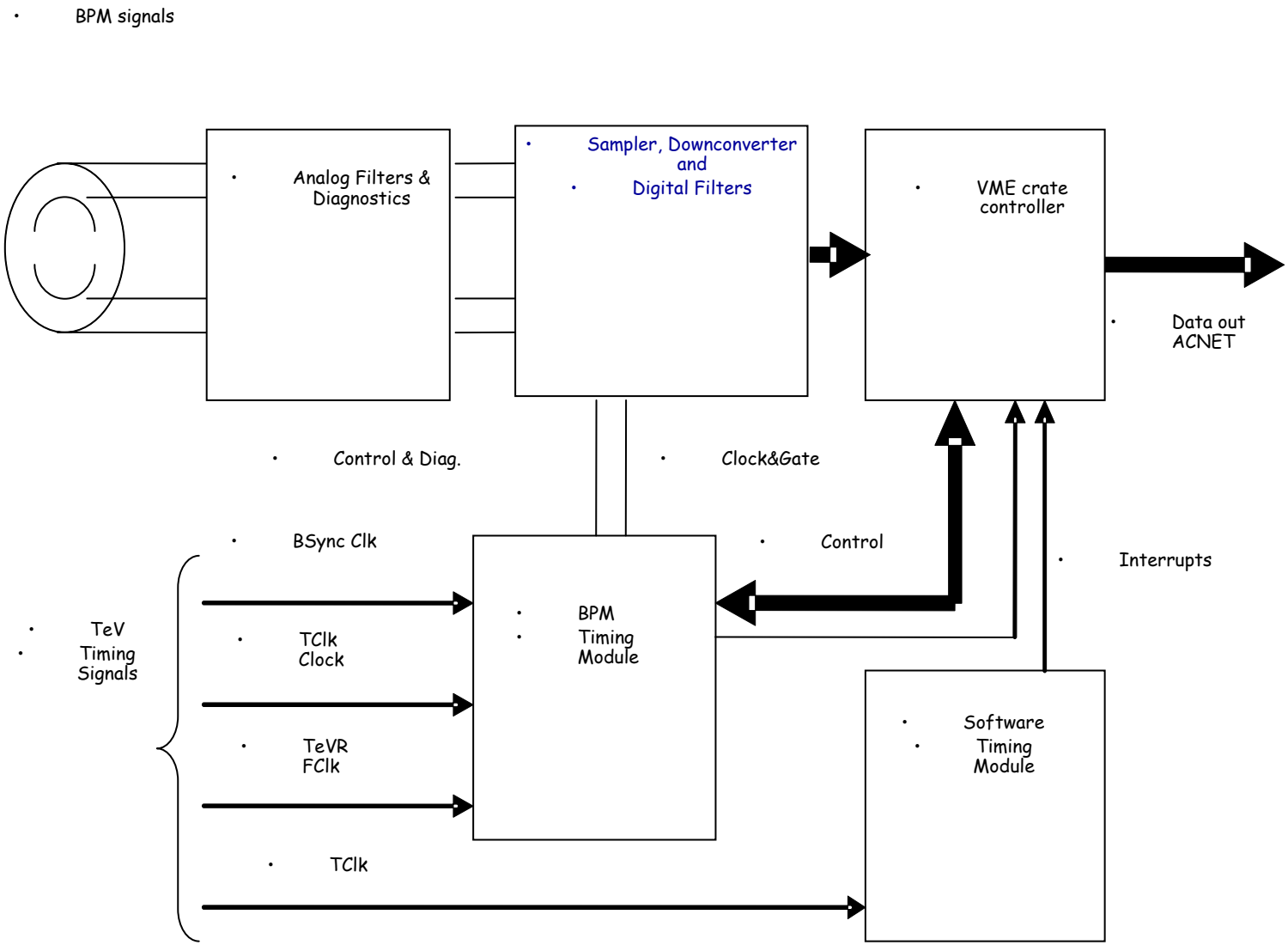
C1
4/15/05

D1
4/15/05



E1
4/15/05

Alternative Block Diagram



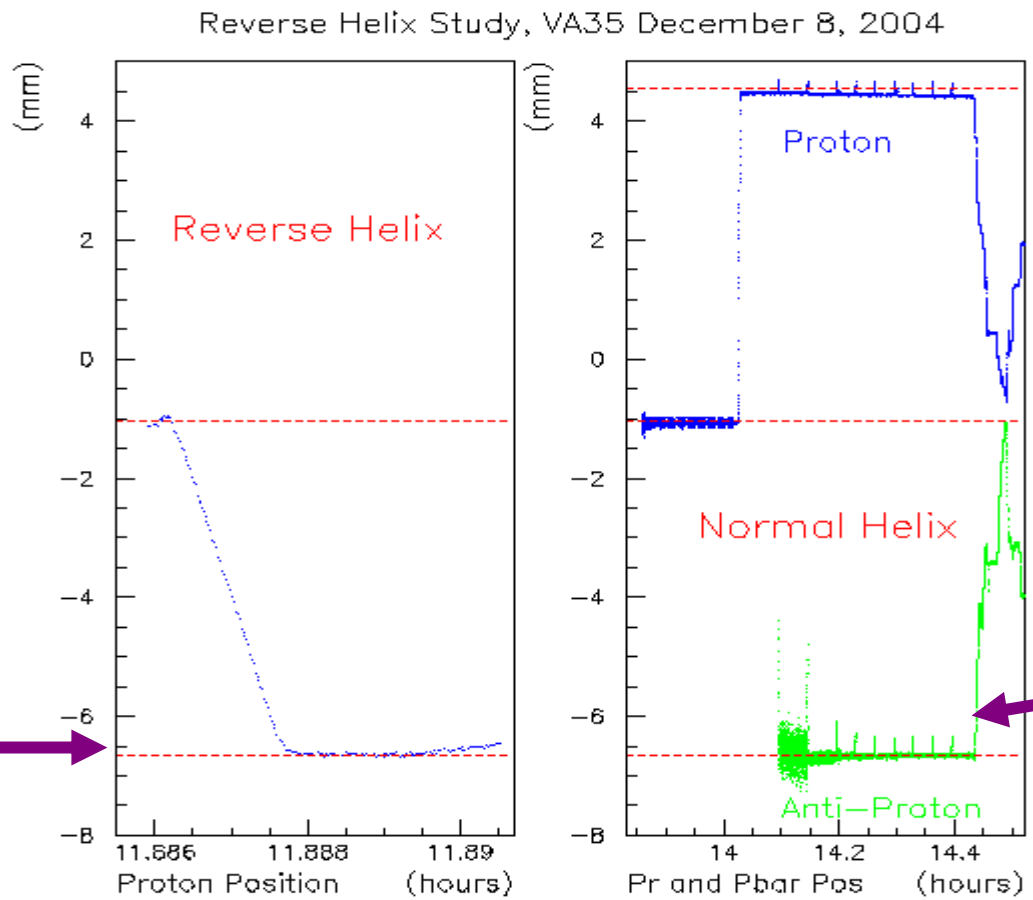
Hardware Components

- Echotek Digital Signal Receiver (150)
  - Commercial 8 channel 80 MHz 14 bit ADC, DDC, FPGA
  - Exact or similar boards are common to Recycler, Transfer Lines, NUMI, MI BPM projects
- Front-end Filter Board (150)
  - 53 MHz band-pass filter, 10 or 20 dB attenuator, relays for diagnostic signal
- Timing Board (38)
  - Provides clocks and triggers for Echotek
  - Provides 53 MHz diagnostic signals
- MVME 2400-0361 Processors, VME subracks, Crate monitoring, cables, test stands, test signals, controls network.

Software Overview

- **Front-end**
  - Processes Echotek output to provide
    - Closed orbit
    - Turn-by-turn
    - Injection first turn
  - Manages data collection and modes of operation.
- **Online/console applications**
  - Moves data into controls system and applications, libraries and databases.
  - Essentially all applications have been modified to use the new data.
- **Offline/calibration**
  - Provides necessary deconvolution (pbar) and corrections to ensure accuracy and precision of the system.
  - pbar measurements will be available at the front-end.

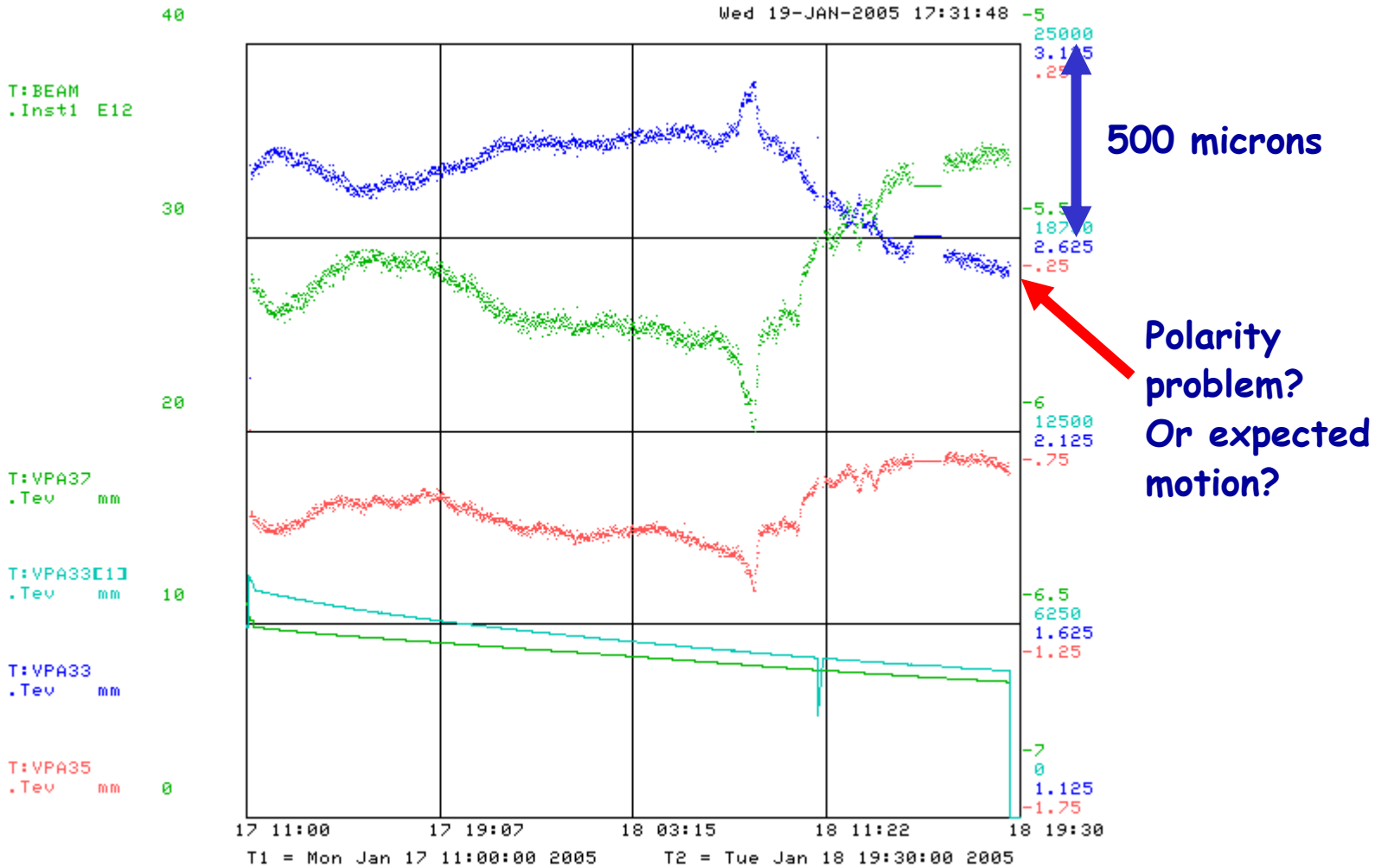
A3 result – pbar, injection



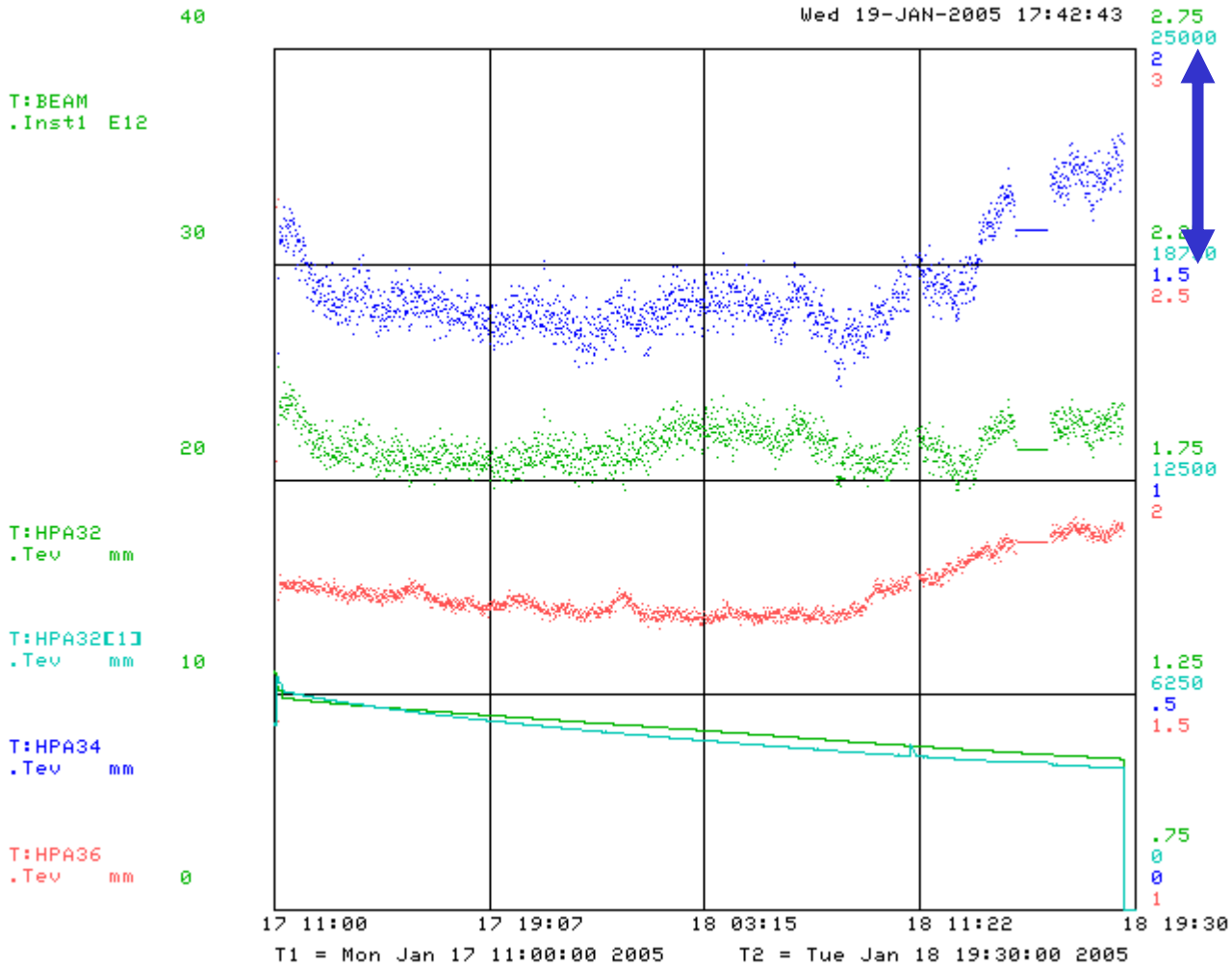
Predicted Pbar position

Measured pbar position

Recent Store (Monday 1/17/05) Vertical

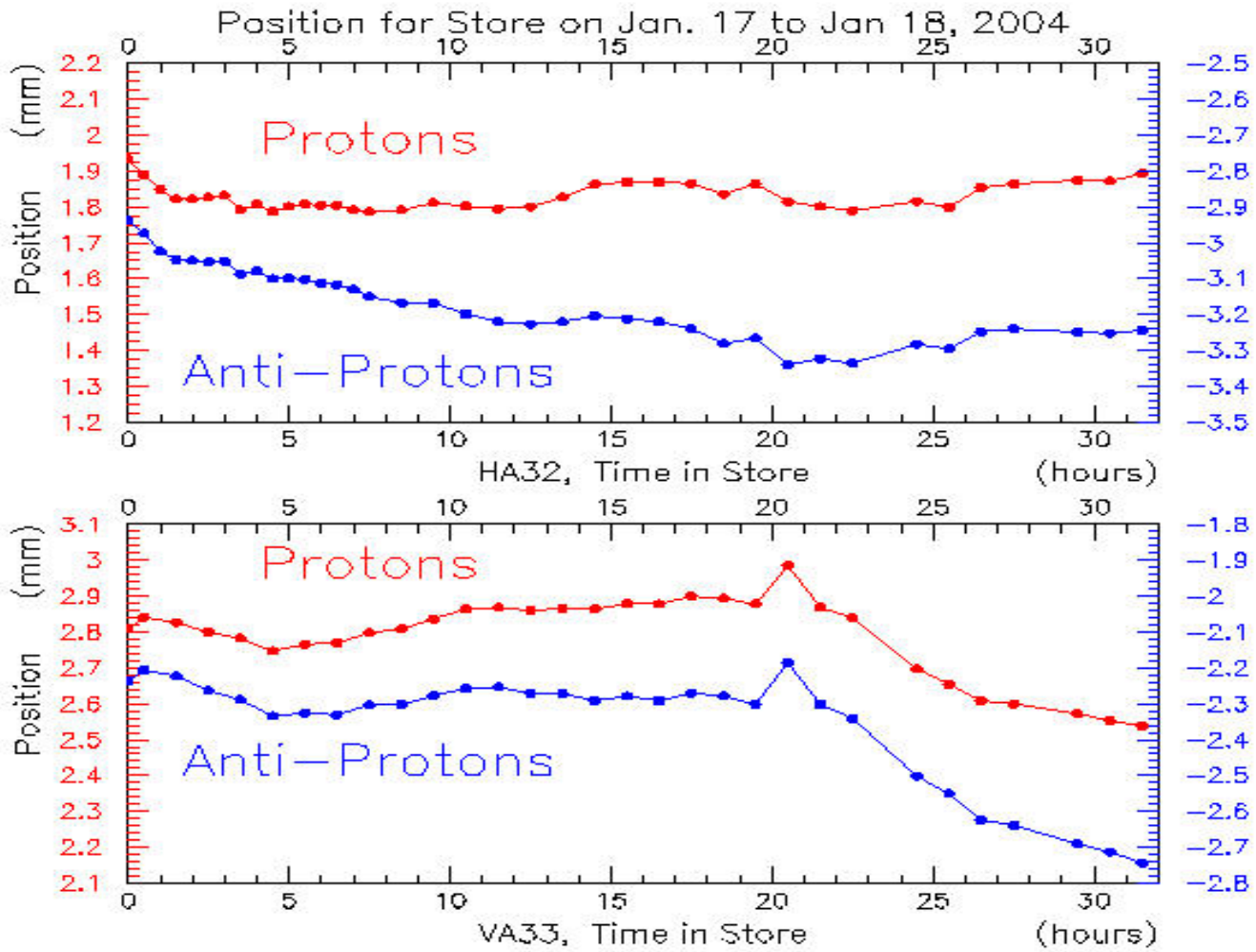


Same store - horizontal



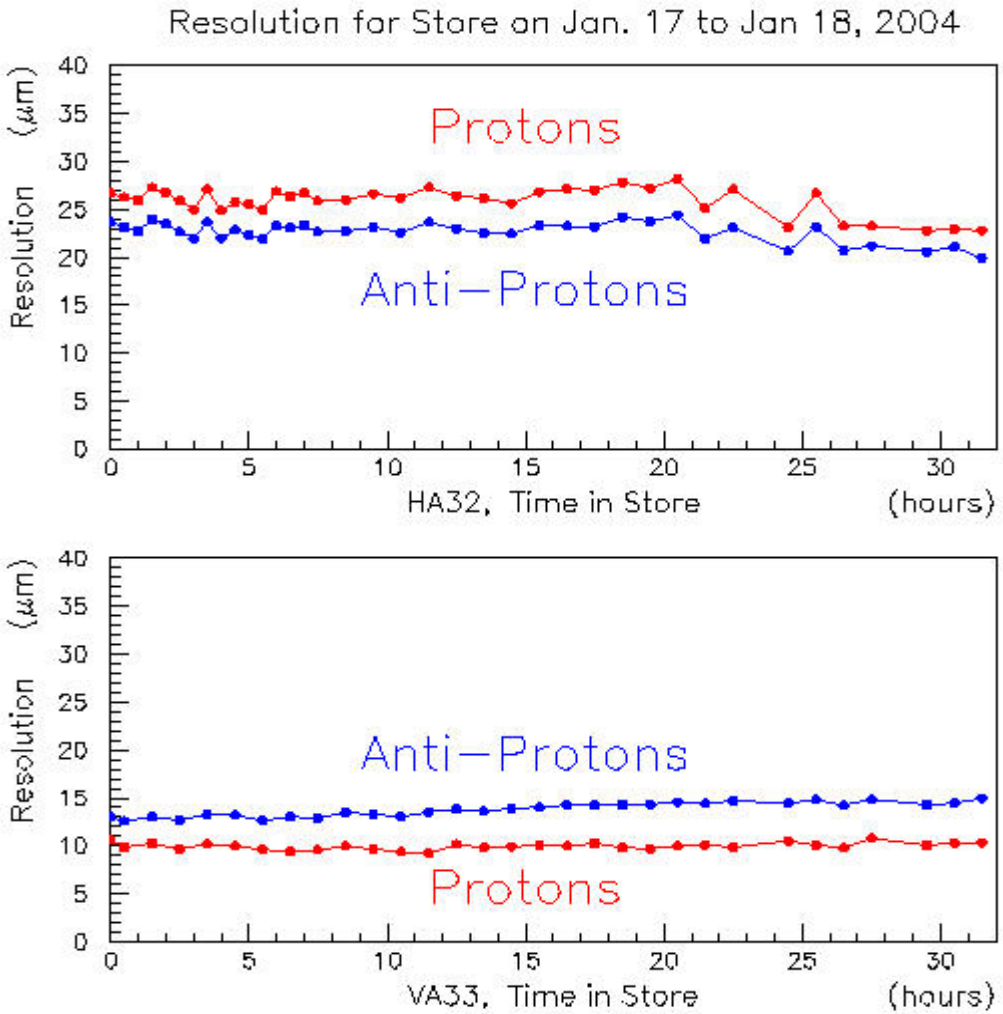
500 microns

p and pbar positions during 1/17/05 store



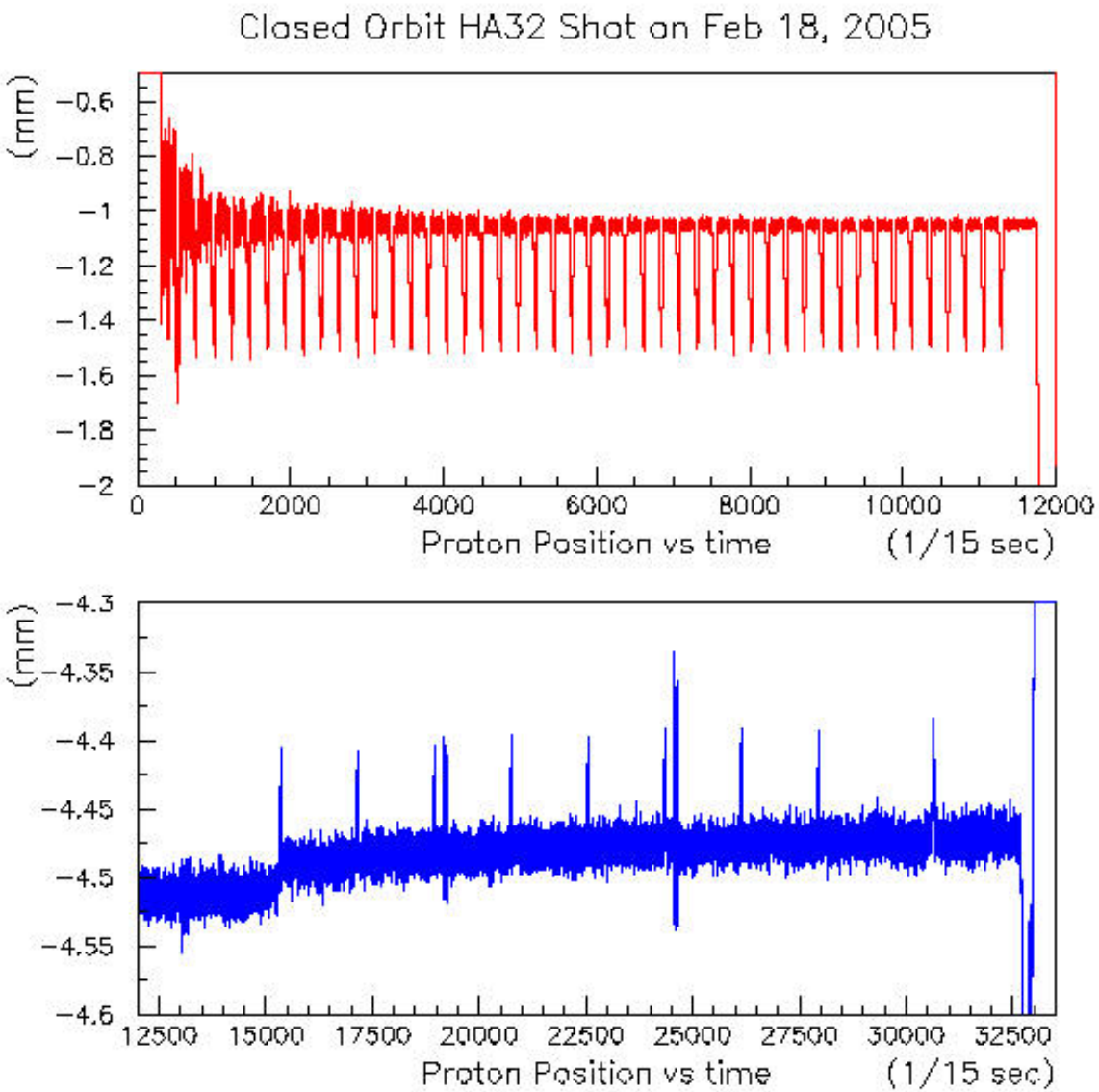
Early results- Still need to Analyze to see If it makes Sense.

P and pbar resolutions (closed orbit) during 1/17/05 store



Horizontal ~20-25 μm (thought to be due to beam motion)

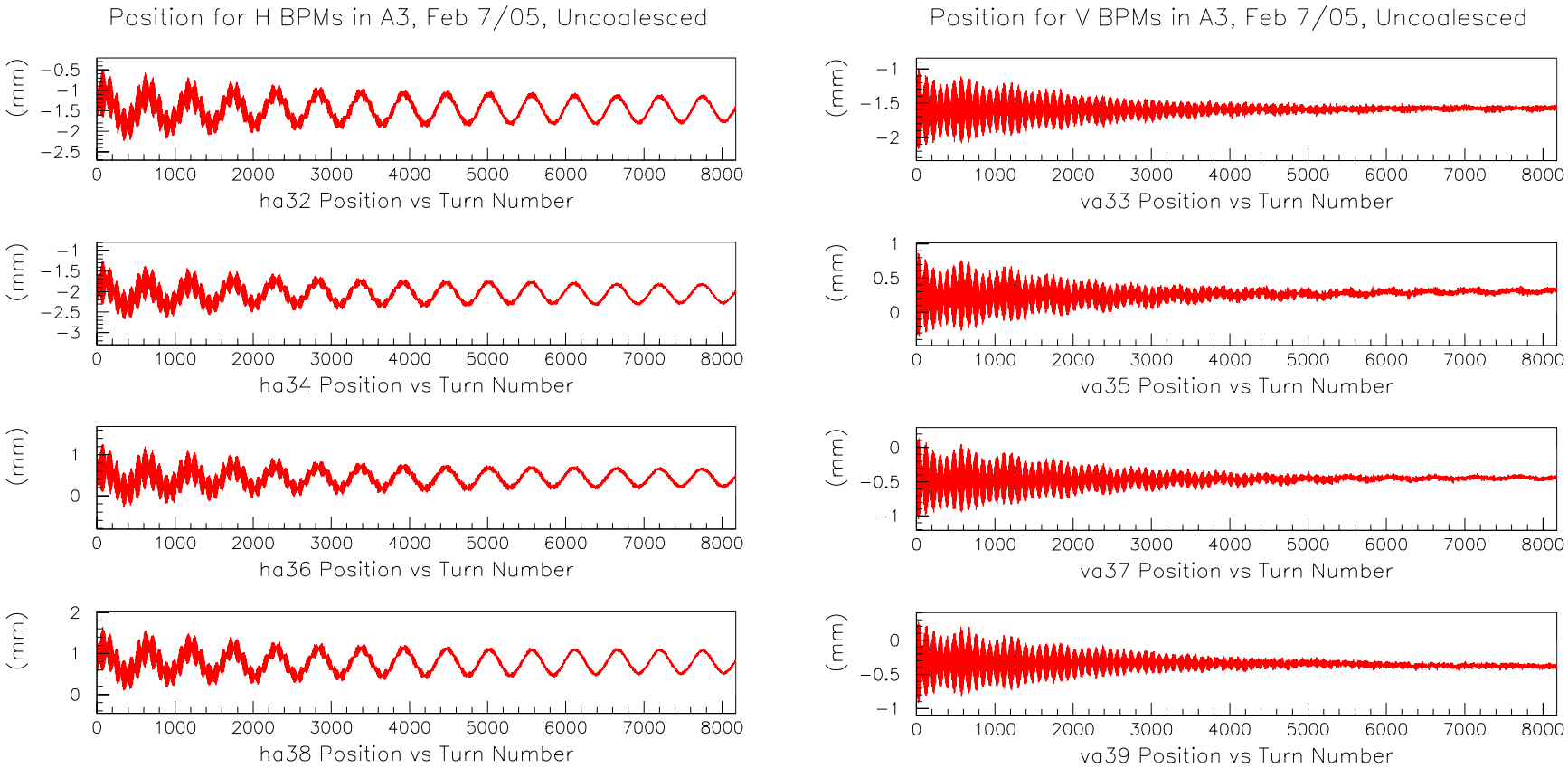
Vertical ~10-15 μm



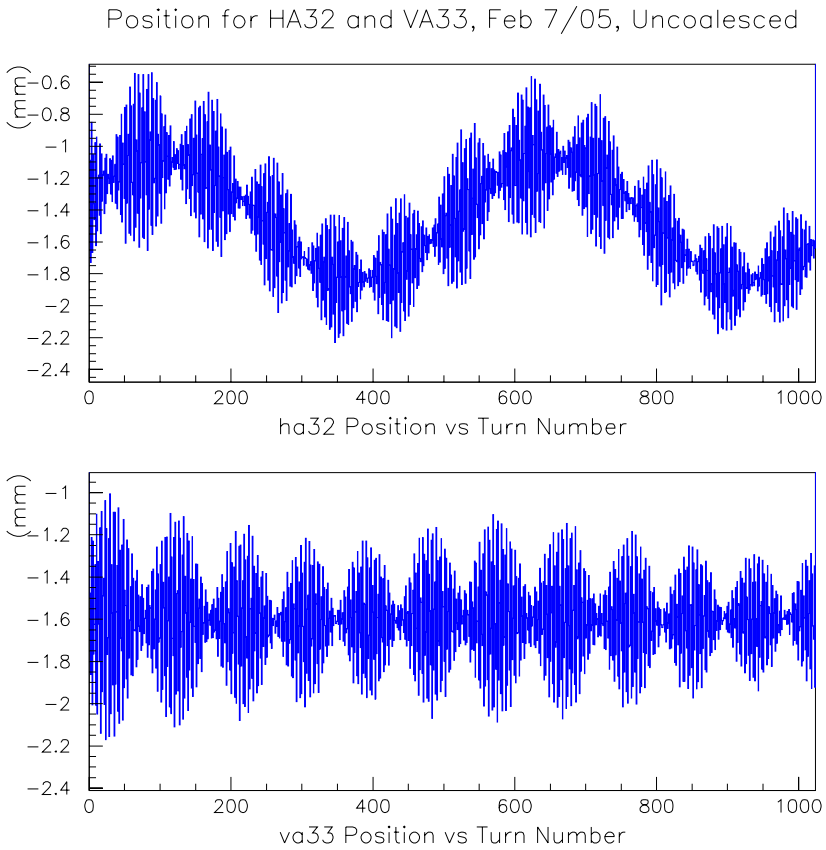
Detail during proton injection and anti-proton injection.

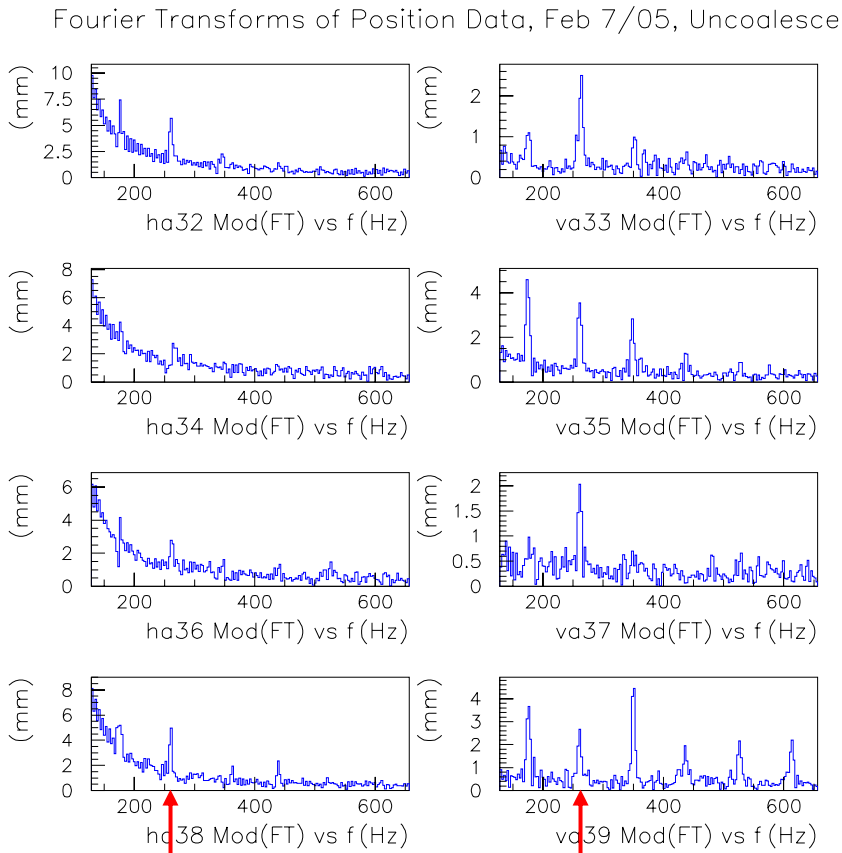
Can see injection bumps during proton injection.

During pbar injection can see injections, cogging and small instrumental effects.



- Injection TBT; 150 GeV; 8192 turns.
- Uncoalesced beam. Tuneup shot with large injection mismatches.





- HV coupling is clear.
- Frequency of envelope is about 260 Hz.

HV Coupling Frequency